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Analysis of Test-Retest Reliability for a Battery of Cognitive Speed Tests

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Subj: **ANALYSIS OF TEST-RETEST RELIABILITY FOR A BATTERY OF COGNITIVE SPEED TESTS**

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1. The present research is an outgrowth of the Cognitive Speed project at the Navy Personnel Research and Development Center (NAVPERSRANDCEN). The project's purpose is to determine whether tests of mental speed could be used to supplement information provided by the current Armed Services Vocational Aptitude Battery. Cognitive speed measures may provide a broader ability profile on which decisions regarding personnel selection and classification could be based.

2. Earlier research at NAVPERSRANDCEN had indicated that speed of information processing is related to mental aptitude (NPRDC TR 86-23) and performance in a technical training program (NPRDC TR 85-3). The present report discusses the test-retest reliability of cognitive speed tests.

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Analysis of Test-Retest Reliability for a Battery of Cognitive Speed Tests

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SUMMARY

Problem

There has been almost no increase in the predictive validity of traditional psychometric tests since they were first put into use more than 60 years ago. Recent developments in the cognitive and computer sciences, such as computerized tests of cognitive (mental) speed, appear to have considerable potential for adding incremental validity to existing aptitude batteries. Little is known, however, about the psychometric characteristics of many of these newer measurement techniques.

Purpose

The purpose of the present study was to determine the reliability (in particular, test-retest) coefficients for a battery of microcomputerized cognitive speed tests. In addition, the validity of such tests was explored.

Approach

A set of four reaction time tests, three inspection time tests, and an experimental test of speed of processing in active memory were administered to 104 male and female college students between 18 and 35-years of age. Seventy-four subjects returned for retesting with 10 days. In addition, all subjects were given a battery of group administered criterion tests. Their scores on the Scholastic Aptitude Test (verbal and math), as well as their high school and freshman grade point averages, were recorded from their official university transcripts.

Results

Test-retest reliability coefficients for the four reaction time tests ranged from .57 to .81. Test-retest reliability coefficients for the three inspection time tasks ranged from .25 to .73, with the highest reliabilities being recorded for the nonadaptive tasks. Test-retest reliability for the speed of processing in active memory (Mental Counters) test was .59. Split-half reliabilities were generally higher than those for test-retest. Validity coefficients were mixed.

Discussion and Conclusions

The following conclusions appear to be warranted from the data.

1. Reaction time (RT) and inspection time (IT) tests load on separate factors, and may have different patterns of validity. Certain tests of each construct have sufficient reliability to justify further development.

2. RT tasks of all types are highly intercorrelated and related similarly to a variety of criterion variables. Consequently, it may not be necessary to have a wide battery of such tasks--one or two well-selected tasks are all that is needed. Of the RT tests administered in the present study, the Arrows test is the best prospect for further research.

3. Of the IT tasks, those involving horizontal lines in a nonadaptive paradigm are by far the most reliable. Increasing the number of trials from 50 to 75 would result in a

better test. A nonadaptive, 75 item horizontal line test and the newer Perceptual Organization IT test both deserve further evaluation.

4. The Mental Counters Test is particularly promising in that it loads on its own factor and thus appears to be tapping into a source of variance different from RT and IT tasks.

5. The continued development and validation of measures of RT, IT, and other variables appears to hold considerable promise for measuring aspects of ability not tapped by conventional psychometric tests.

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INTRODUCTION

There has been almost no increase in the predictive validity of traditional psychometric tests since they were first put into use more than 60 years ago (Rundquist, 1969). The development of economical high speed microcomputers and recent research in cognitive psychology have, however, led to a new approach of considerable promise: cognitive assessment. Cognitive assessment is based on theories of information processing, which view mental ability in terms of a number of underlying component processes (e.g., sensory input, mental transformations of data, storage, etc.). One attempts to determine the importance of various component mental processes to individual differences in ability.

One branch of cognitive assessment emphasizes mental speed. There appear to be two fundamentally different ways of timing elementary mental processes via microcomputer: one based on reaction time (RT); the other based on a measure of information processing (mental) speed called inspection time (IT) (Vernon, 1986).

In the RT tasks, the subject is asked to respond as quickly as possible following the presentation of a stimulus. The nature of the task varies from simple RT, in which the subject merely responds as quickly as possible following the onset of a single stimulus, to complex (i.e., choice) RT, in which decisional processes are involved. It is well known that multiple-choice RT increases as a linear function of the logarithm (to base 2) of the number of choices, a phenomenon known as Hick's Law (Hick, 1952; Jensen, 1986). The slope of this function is generally regarded as an inverse measure of speed of processing. A number of studies have found a modest (median about .4) but consistent correlation between a variety of RT tasks and traditional psychometric intelligence tests (Carlson & Jensen, 1982; Carroll, 1980; Vernon & Jensen, 1984). Reported reliabilities for various RT tasks vary, but fall within very acceptable limits. Jensen (1982) reports that the typical test-retest reliabilities from his lab run about .75. Krause and Bittner (1982) report test-retest coefficients of .58, .51, and .80 for a one, two, and four RT task, respectively. Other studies report similar correlations, with a range of coefficients from the low .5s to the low .8s and median in the mid .7s (e.g., see Bittner, Carter, Kennedy, Harbeson, & Krause, 1984; Carroll, 1980; Harbeson, Kennedy, Krause, & Bittner, 1982; Kyllonen, 1986; Rose & Fernandez, 1977). Split-half reliabilities for simple and choice RT tasks typically run above .90 (see Vernon, 1983).

In IT tasks, subjects are presented with increasingly rapid stimulus presentations. Mental (cognitive) speed is evaluated in terms of a subject's ability to respond accurately to such presentations rather than in terms of speed of response in pressing an appropriate key as in RT tasks (Vernon, 1986; Vickers, Nettelbeck & Wilson, 1972; Vickers & Smith, 1986). For example, two lines of unequal length may be presented at varying speeds. Following termination of the line stimuli there immediately follows a visual backward mask, which limits stimulus processing (Felsten & Wasserman, 1980; Saccuzzo, Larson, & Rimland, 1986). IT is based on the fastest speed at which a subject obtains a criterion degree of correct identifications of thee longer line. A large body of literature has documented a modest but clear-cut relationship between intelligence and both RT and IT time measures of cognitive speed, supporting the potential of these relatively new measures in cognitive assessment (Longstreth, Walsh, Alcorn, Szeszulski, & Manis, 1986; Nettelbeck, Edwards, & Vreugdenhil, 1986; Saccuzzo, Larson, & Rimland, 1986).

Based on a number of small sample studies conducted at their lab, Brand and Deary (1982) report that the typical reliability coefficient for inspection time is .8, a figure in accord with a report by Vernon (1983), who also reports a test-retest reliability coefficient of .8 for an IT task. As Nettelbeck (1983) noted, however, to date there has yet to be a reliability study that has used a reasonable large sample. In a review of the literature, Nettelbeck (1982, 1983) found 36 instances involving non-retarded adult samples (usually university students) that ranged in size from 10 to 56 subjects; reliability coefficients for IT ranged from .25 to .92, with an average of .65. As Nettelbeck points out, however, the vast majority of these coefficients are based on repeated measures taken within a single session, or at most, within a day or two. On the whole, correlations have been least impressive for larger sample sizes and longer test-retest intervals.

In summarizing the limited data on RT and IT tasks, two major conclusions emerge. First, tests involving simple and choice reaction time are highly reliable for indices based on response latencies. Median reported test-retest coefficients run in the mid .7s, while internal consistency coefficients run in the high .9s. Second, on the whole, the reliability for IT appears to be lower than for RT, but within acceptable limits. However, more work on larger samples is needed.

The primary purpose of the present study was to provide test-retest reliability data on a battery of microcomputerized cognitive speed tasks developed by researchers at the Naval Personnel Research and Development Center (NAVPERSRANDCEN), San Diego. The battery includes a number of standard RT and IT tasks, adapted for microcomputer presentations, as well as a number of experimental complex RT tasks (the Arrows Test and a RT paradigm not involving movement time), an experimental IT task (a perceptual organization task), and a measure of storage and processing speed in active memory called the Mental Counters Test (MCT) developed by Larson (in preparation). In addition, a number of questions were addressed. In particular, this study attempted to evaluate: (1) the relative reliabilities of different approaches to evaluating IT (i.e., adaptive versus nonadaptive), (2) the effect of increasing task complexity on subject performance, and (3) the validity of RT and IT measures.

All of the tasks chosen for study were nonverbal, knowledge free, and involved minimal response requirements (i.e., all a subject was required to do was press an appropriate key on the microcomputer keyboard). They varied primarily in terms of complexity and whether the task emphasized response speed or response accuracy.

METHOD

Subjects

The subjects were 104 volunteer San Diego State University students from an introductory course in psychology. They ranged in age from 18 to 35-years-old (M = 21.39, SD - 3.72). The majority of subjects were 19-years-old (N = 29), 20-years-old (N = 24), or 21-years-old (N = 13). There were 49 males and 55 females. Eighty-four were Caucasian, 7 Hispanic, 2 Black, 6 Asian, and 5 "other." The sample was representative of San Diego State University students.

Procedure

Each subject was tested on a battery of microcomputerized tests. Presentation of these tests was completely randomized for each subject according to a prearranged random sequence. Three types of tasks were used: (1) IT, (2) RT, and (3) Mental Counters.

1. Inspection Time Tasks. There were three IT tasks: (a) Inspection Time Test-Adaptive (IT-Adaptive), (b) Inspection Time Test-Nonadaptive (IT-Nonadaptive), and (c)

the Perceptual Organization Test (PO Test). For all IT tasks, a visual stimulus was briefly presented. Immediately following stimulus termination, a backward visual noise mask was presented. The mask is known to limit the duration of the sensory signal delivered to the central nervous system (CNS) (Felsten & Wasserman, 1980). The subject's task was to make a forced-choice discrimination by pressing one of two buttons on the microcomputer keyboard. Each of these three IT tasks is briefly described below.

a. Inspection Time Test-Adaptive (IT-Adaptive)

The IT-Adaptive was an IBM-PC presented version of the task used by Larson and Rimland (1984). In this task, subjects are briefly shown two lines of unequal length, which are presented in the center of the cathode ray tube (CRT) screen. The subject's task is to identify the longer line by pressing an appropriate key on the keyboard. The longer line is randomly presented either to the right or left of central fixation on any given trial. Thus, the task involves a forced-choice visual discrimination. To control for individual differences in visual persistence and for the duration of the sensory signal delivered to the CNS, presentation of the lines is immediately followed by a visual noise mask consisting of a solid parallel line that completely superimposes the target line stimuli. The duration of the target line stimuli was varied, depending on subject performance. Presentations began with an initial display duration of 317.3 msec. In the display duration algorithm, if a subject made three consecutive correct responses, he or she was allowed to attempt the next higher level of difficulty. If, however, the subject made an error, the test decreased in difficulty (i.e., the stimulus duration was increased). If the subject made three consecutive responses at the briefest display duration possible on the CRT screen (16.7 msec.), the testing was terminated and the subject was assigned a score of "0." Otherwise, testing continued until the subject made a total of three errors; the subject's score was then based on the final display speed, with lower scores denoting better performance. The test was administered twice; once with vertical lines as test items (line lengths of 20.6 mm. and 14.3 mm.), and once with horizontal lines (17.5 mm. and 14.3 mm.). Although the line lengths differed between orientations, a smaller disparity was employed in the horizontal condition due to results from pilot testing, which indicated that the discrimination was easier for horizontal lines.

b. Inspection Time Test-Nonadaptive (IT-Nonadaptive)

The IT-Nonadaptive was identical to the above procedure with the exception that the sequence of stimulus durations used was fixed in advance, rather than dependent on subject performance. Subjects began with 10 trials of either horizontal or vertical lines for each of five display speeds: 16.7, 33.4, 66.8, 100.2, and 150.3. Order of presentation of display speeds was completely randomized for each trial, with the exception that no more than 10 trials would occur for any given stimulus duration within a total of 50 trials. After the first 50 trials, the entire procedure was repeated using horizontal lines if the subject began with vertical lines and vice versa. Thus, subjects had a total of 100 trials, 20 at each of five different stimulus durations.

c. Perceptual Organization Test (PO Test)

The PO Test is a variation of IT in which the discrimination must be made between briefly displayed patterns of dots organized into either rows or columns. The rationale for the PO Test is based on a series of studies that revealed a relationship between tested intelligence and performance on a tachistoscopic version of the test (De Soto & Leibowitz, 1956; Krech & Calvin, 1953). As with the IT-Nonadaptive Test, stimulus are randomly presented at any one of five display speeds: 16.7, 50.1, 83.5, 167, and 334 msec. Immediately following termination of the pattern display, a spatially overlapping, nonpatterned cluster of dots was presented, providing a visual backward mask that limited the duration of the sensory signal delivered to the central nervous system. There were 15 trials per display speed, with order of presentation completely randomized. At the beginning of each trial, subjects were instructed to attend to a fixation point in the center of the screen. After one second, a dot pattern, approximately 16 mm. square, was presented next to fixation, offset in the direction of one of the four screen corners, but overlapping with fixation so that one of the corners of the stimulus pattern was anchored to screen center. The pattern was made of dots spaced approximately 4 mm. apart. Subjects were instructed to respond by pressing an appropriate key, depending on whether they had perceived an upright (columns) or sideways (rows) pattern.

2. <u>Reaction Time Paradigms</u>. Four RT paradigms were used: (a) Hick Paradigm with movement time for 1, 3, and 5 choices; (b) Hick Paradigm without movement time for 1, 3, and 5 choices: (c) the Arrows Test; and (d) a two choice reaction time test for central, right, and left visual field presentations. Each of these is briefly described below.

a. <u>Hick Paradigm with Movement Time for 1, 3, and 5 Choices</u>

This paradigm is essentially the same as that employed in previous research (see Larson & Rimland, 1984; Saccuzzo et al., 1986). A horizontal arrangement of lights was presented at the bottom of the CRT screen, and the top row of keys on the keyboard (one key paired with each stimulus light) was used for responding. All subjects were presented with 1-, 3-, and 5-choice conditions, with order of presentation completely randomized. Open squares on the CRT screen were used as stimulus lights, and subjects were instructed to respond by first pressing the space bar and then pressing the appropriate key as quickly as possible after a square became illuminated. There were 21 trials at each condition. At the beginning of each trial, subjects rested the forefinger of their dominant hand on the space bar at the bottom of the keyboard. After a random period of time (1.5 to 2.5 seconds), one of the stimulus squares was illuminated. Reaction time was the number of msec. between the onset of the stimulus (i.e., when one of the stimulus squares was illuminated) and the instant the subject pressed the space bar. Movement time was the number of msec. between pressing the space bar and striking a response key. If a reaction time greater than 2 seconds was recorded, the trial was discarded and a new one presented to maintain a total of 21 trials per condition. A count was kept of discarded trials.

b. <u>The Arrows Test</u>

In the Arrows Test (Larson, 1985), subjects were instructed to fixate on two small circles presented side by side in the center on the CRT screen. For each trial, one of the circles was replaced by an arrow, and, depending on its direction and position, the subject responded by pressing either a right or left key on the microcomputer keyboard. If the arrow pointed down, its position indicated the appropriate response. For example, if a downward arrow replaced the right circle, the right key was pressed. If a downward pointing arrow replaced the left circle, then the left key was pressed. If an arrow pointing sideways (i.e., right or left) was present, then direction became the relevant cue, while position became a distractor. If the arrow pointed right, the right key was pressed. If it pointed left, the task was to press the left key as soon as possible. RTs greater than 2 seconds were discarded and new items presented to maintain a constant number of trials per subject. A count was kept of discarded trials. The position and direction of the arrow were varied randomly. The test involved 82 trials; 41 with downward arrows and 41 with right-left arrows.

c. Two Choice Reaction Time Test for Central, Right, and Left Visual Field Presentations

In the two choice reaction time test for central, right, and left presentations, subjects were randomly presented with either of the following two patterns: "X:*:X" or "X:+:X." The patterns were presented at three screen locations. On 50 percent of trials, the pattern appeared at a fixation point in the middle of the screen, so that the central element of the pattern ("*" or "+") replaced the fixation point. For the remaining trials, the patterns were presented at either the far left or far right of the CRT screen. Thus, detection required a visual shift from the central fixation point to the site of the item. If a RT greater than 2 seconds for any condition was recorded, the trial was discarded and a new one presented to maintain a constant number of trials per subject, per condition. A count was kept of discarded responses. The test involved 80 trials; 40 at fixation (screen center), 20 at screen right, and 20 at screen left. By subtracting RT at center from RT at periphery, the time required to make a visual shift was isolated, since all other processes involved in visual encoding and response selection and execution are presumed to be equal across screen locations.

3. Mental Counters Test (MCT). In the MCT (Larson, in preparation), subjects must keep track of the values of three independent "counters." The values change rapidly and in random order. The difficulty of the task comes from having to simultaneously hold the three counter values in memory, rapidly update those values as necessary based on a simple arithmetic calculation, and store the new values. If counter updating is performed too slowly, the adjustments themselves must be remembered, even as new calculations are required. Individuals who must store too many adjustments because of slow execution will eventually experience a "breakdown" as capacity is exceeded.

The counters themselves are represented as lines on the video monitor (three side by side horizontal dashes in the center of the screen). The initial counter values are zero. When a target (a small box) appears above a dash, the corresponding counter must be adjusted by adding "1." When the target appears below one of the three dashes, the corresponding counter must be adjusted by subtraction "-1." The test items vary both in the number of targets (i.e., number of counter adjustments) and in rate of presentation. There were two levels of counter adjustments (five and seven) and two levels of rate of presentation (fast and slow). The actual test involved a total of 40 trials. On 20 trials, 5 targets were presented. Seven targets were presented on the remaining 20 trials. On 20 trials, targets were presented at the rate of one every .25 of a second. On the remaining 20 trials, targets were presented at the rate of one every .83 of a second. Number of targets and rate of presentation were completely counterbalanced.

Table 1 presents a summary of the microcomputerized tests.

All microcomputerized tests were presented on IBM PC/XT microcomputers with color monitors and standard keyboards. No special add-ons were used other than color labeling of response keys. Total testing time for the entire battery of tests was approximately 1 hour and 20 minutes.

Table 1

Summary of Microcomputerized Tests and Acronyms

Test	Acronym or Brief Name
Inspection Time Test-Adaptive	IT-Adaptive
Inspection Time Test-Nonadaptive	IT Non-Adaptive
Perceptual Organization Test	PO Test
Hick Paradigm with Movement for	
1 Choice	Hick Move 1
3 Choices	Hick Move 3
5 Choices	Hick Move 5
Hick Paradigm Without Movement for	
1 Choice	Hick No Move 1
3 Choices	Hick No Move 3
5 Choices	Hick No Move 5
Arrows Test	Arrows
Two Choice Reaction Time Test for	
Central	Choice RT
Right	Right Choice RT
Left	Left Choice RT
Mental Counters Test	MCT

Since the primary purpose of this study was to evaluate the test-retest reliabilities for the microcomputerized tests, subjects were invited to return for a retesting. Only those subjects who could be retested within a period of not less than 24-hours, but not more than 10 days, were retested. Seventy-four subjects met this criterion and were retested.

Group Criterion Tests

During the course of the study, each of the original 104 subjects were given the following five group administered criterion tests.

1. The P3 test (Identical Picture Test) of the kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harman, 1976). The P3 test requires subjects to match simple figures. It evaluates a subject's speed in carrying out simple tasks involving perceptual scanning.

2. The S1 test (Card Rotations Test) of the kit of Factor-Referenced Cognitive Tests. A measure of spatial orientation--the ability to perceive spatial patterns or maintain orientation with respect to objects in space. The S1 tests requires mental rotation of figures.

3. The VZ3 (Surface Development Test) of the kit of Factor-Referenced Cognitive Tests. This is the highest loading test of the Visualization Factor, which is defined as the ability to manipulate or transform the images of spatial patterns into other arrangements.

4. The Cognitive Laterality Battery (CLB), developed by Gordon (1983) to evaluate individual differences in hemispheric asymmetries. The CLB is a slide projected battery of eight individual subtests. Presentation of the battery is driven by cues embedded in cassette tapes, which contain instructions and auditory test items. Of the eight subtests, four are nonverbal and purportedly related to right hemisphere functioning; the other four are related to left hemisphere functioning. An overall Right Hemisphere (RH) score is the average of the Z-scores for the four right-hemisphere-related subtests; an overall Left Hemisphere (LH) score is the average of the Z-scores for the four left-hemisphere-related tasks.

5. The Raven Progressive Matrices Test, Advanced, group administered (40 minute time limit).

In addition, each subjects' score on the Scholastic aptitude Test, Verbal (SATV) and Math (SATM), as well as high school grade point average (HSGPA) and freshman grade point average (FRGPA) were recorded from their official transcripts. Table 2 provides a summary of the criterion measures.

Table 2

Summary of Criterion Measures and Acronyms

Variable	Measure of	Acronym
Identical Picture Test	Perceptual Speed	P3
Card Rotations Test	Spatial Orientation	S1
Surface Development Test	Visualization	VZ3
Gordon Cognitive Laterality Battery Overall Right Hemisphere	Right Hemisphere Functioning	GRH
Gordon Cognitive Laterality Battery Overall Left Hemisphere	Left Cerebral Hemisphere	GLH
Raven Progressive Matrices Test	Intelligence	Raven
Scholastic Aptitude Test, Verbal	Scholastic Aptitude (Verbal)	SATV
Scholastic Aptitude Test, Math	Scholastic Aptitude (Mathematics)	SATM
High School Grade Point Average	School Achievement	HSGPA
Freshman Grade Point Average	School Achievement	FRGPA

RESULTS

Table 3 presents the means and standard deviations for each of the criterion variables as well as their intercorrelations. In examining these correlations, it is notable that the Raven Progressive Matrices Test correlated well with the S1, VZ3, and Gordon Right Hemisphere Tests. The only significant correlate of the SATV was the SATM ($r = .28$).

Table 3

Means, Standard Deviations, and Intercorrelation
Among Criterion Variables

	P3	S1	VZ3	GRH	GLH	Raven	SATV	SATM	HSGPA	FRGPA
P3	1.0	.35**	.39**	.26*	.18	.25*	-.07	-.05	.12	-.05
S1	--	1.0	.37**	.07	.05	.32*	.20	.28*	.45**	.18
VZ3	--	--	1.0	.45**	-.00	.54**	.16	.41**	.24*	.18
GRH	--	--	--	1.0	.12	.36**	.03	-.02	-.02	.12
GLH	--	--	--	--	1.0	.05	.15	.14	-.20	-.09
Raven	--	--	--	--	--	1.0	.18	.47**	.11	.01
SATV	--	--	--	--	--	--	1.0	.28*	.07	-.02
SATM	--	--	--	--	--	--	--	1.0	-.08	.10
HSGPA	--	--	--	--	--	--	--	--	1.0	.54**
FRGPA	--	--	--	--	--	--	--	--	--	1.0
Mean	80	103	30	-.05	.18	22	438	499	2.8	2.2
SD	12	33	15	.96	.69	5.45	76	89	.65	.84

*$p < .05$.
**$p < .01$.

In analyzing the data for the computerized tests, a number of preliminary analyses were conducted to determine the best or most representative indices for each. For the adaptive IT test, results from the vertical and horizontal versions were converted to Z-scores and averaged to form a composite score, labeled IT-Adaptive. For the IT-Nonadaptive test, test-retest reliabilities were calculated separately for each of the five stimulus durations for the vertical and horizontal versions. In addition, a weighting scheme was explored in which points were assigned for correct responses to an item as a linear function of that item's display duration. The two weighted scores (one for the vertical version and one for the horizontal version) were converted to Z-scores and averaged to form a composite. Finally, a simple measure based on the total correct, also based on average Z-scores for the vertical and horizontal tests, was evaluated. Table 4 presents the various test-retest reliabilities for each of these measures. The simple measure based on total correct was found to be of higher reliability than either weighted score and, labeled IT-Nonadaptive, is used throughout the remainder of the analysis. It should be noted, however, that the task involving horizontal lines ($r_{xx} = .66$) was clearly more stable than the task based on vertical lines (r_{xx} .41).

Table 4

Test-Retest Reliabilities for Various Indices of IT-Nonadaptive

	Reliability Coefficient[a]
Horizontal Lines	
16.7 msec. duration	.27*
33.4 msec. duration	.20*
66.8 msec. duration	.43**
100.2 msec. duration	.64**
150.3 msec. duration	.59**
Total correct based on horizontal lines	.66**
Vertical Lines	
16.7 msec. duration	.01
33.4 msec. duration	.11
66.8 msec. duration	.12
100.2 msec. duration	.29*
150.3 msec. duration	.57**
Total correct based on vertical lines	.41**
Weighted score based on horizontal lines	.49**
Weighted score based on vertical lines	.22*
Weighted score based on both horizontal and vertical lines	.39**
Total correct based on both horizontal and vertical lines	.55**

[a]N = 72.
*$p < .05$.
**$p < .01$.

For the perceptual organization test, test-retest reliabilities were determined for the total correct at each of the five stimulus durations. These were, from the lowest to the highest durations, respectively, .41, .54, .54, .56, .59 (based on an N of 74 valid cases). A derived weighted score, which gave subjects more points for correct responses on more difficult items, had a test-retest coefficient of .56. The best index, however, was based on the total correct across the entire test ($r_{xx} = .73$) and this index is used throughout the remainder of the analyses.

All reaction time indices were based on the median response latencies. For the Arrows Test, two such latencies were included, Arrows Down (median latency for arrows that pointed downward) and Arrows Side (median latency for arrows that pointed right or left). For the two choice reaction time test, three indices were calculated: median latency for central presentation ($r_{xx} = .74$), median latency for left presentations ($r_{xx} = .67$), and the median latency for right presentations ($r_{xx} = .58$). Because of the extremely high intercorrelations among these three indices, however, only the central presentations measure, labeled simply "Choice RT," is included in the subsequent analyses.

Table 5 shows the test-retest reliabilities for the various indices of the MCT. The index based on the total correct for all trials provided one of the best measures, and is used throughout the remainder of the analysis and is labeled MCT.

Table 5

Test-Retest Reliabilities for the Mental Counters Test

	Reliability Coefficients[a]
Slow speed, seven indicators	.50*
Fast speed, seven indicators	.49*
Slow speed, five indicators	.55*
Fast speed, five indicators	.41*
Seven indicators, total correct	.47*
Five scores, total correct	.62*
Total correct based on all trials	.59*

[a]N = 74.
*$p < .001$.

Table 6 provides an overall summary of the means, standard deviations, and test-retest reliability coefficients for each of the major indices. Examination of Table 6 reveals that, with the exception of IT-Adaptive, all of the test-retest reliabilities were greater than .55. Overall, reliabilities were greater for reaction time tasks, as compared to the inspection time tasks and the MCT.

Table 6

Means, Standard Deviations, and Reliability Coefficients for Computerized Tests

Test	M1	M2	SD1	SD2	r_{xx}[a]
Inspection Time					
Adaptive	-0.03	-0.02	0.74	0.81	.25*
Nonadaptive	0.33	0.04	0.77	0.50	.55*
Perceptual organization	65.74	66.88	6.00	7.42	.73*
Hick Paradigm					
RT with movement					
1 choice	310.53	294.16	63.82	62.55	.62*
3 choices	395.73	373.51	79.90	73.16	.72*
5 choices	430.44	419.39	92.28	100.32	.75*
RT without movement					
1 choice	271.29	261.64	61.03	43.18	.59*
3 choices	322.34	321.07	61.46	75.23	.65*
5 choices	352.58	359.01	74.96	92.62	.57*
Arrows Test					
Down median	487.19	440.04	77.10	75.46	.73*
Side median	551.14	500.68	101.26	98.33	.81*
Choice RT	550.70	530.43	65.41	73.67	.74*
Mental Counters Test	26.81	29.74	7.16	6.18	.59*

[a](N = 74).
*$p < .01$.

Split-half reliability coefficients are presented in Table 7. The table includes coefficients based on the total sample as well as on only that subset of the total sample that was retested. Because of the method used to calculate IT-Adaptive, it was not possible to compute split-half coefficients for this test. Similarly, it was not possible to calculate split-half coefficients for composite scores. Examination of Table 7 reveals that the split-half coefficients are generally higher (except for IT-Nonadaptive, vertical lines) then the test-retest coefficients for all variables for which the split-half reliability coefficient was determined.

Table 8 provides a summary of the tests of significance for the difference between the means of first and second testing (first session minus second session). As the table shows, significant practice effects were found for mental counters and several of the RT indices, but not for IT. With the exception of 5 choice RT without movement, all practice effects indicate improvement in performance.

Table 7

Split-Half Reliability Coefficients

Test	Full Sample[a]	First Session[b]	Second Session[b]
IT-Nonadaptive (Horizontal lines)	.77	.73	.77
IT-Nonadaptive (Vertical lines)	.36	.26	.54
Perceptual Organization Test	.64	.67	.79
Arrows Test	.95	.96	.95
Mental Counters Test	.77	.79	.68
Hick with movement			
1 choice	.71	.75	.71
3 choices	.73	.72	.74
5 choices	.72	.75	.86
Hick without movement			
1 choice	.78	.74	.74
3 choices	.87	.84	.85
5 choices	.75	.73	.78

[a]N = 104.

[b]Includes only subjects who were tested both times, N = 74.

Table 8

Summary of t-tests for First and Second Testings

	Difference Between Means	SD	T-Value	Df	2-Tail Prob.
Inspection Time[a]					
Adaptive					
Horizontal	-0.83	4.49	-1.55	69	NS
Vertical	-0.35	4.11	-0.67	70	NS
Nonadaptive					
Horizontal	0.39	5.07	0.64	69	NS
Vertical	-0.24	7.26	-.26	70	NS
Perceptual organization	-1.14	4.95	-1.95	71	NS
Hick Paradigm					
RT with movement					
1 choice	16.08	54.94	2.50	72	$p < .01$
3 choices	22.54	57.58	3.37	73	$p < .001$
5 choices	11.06	68.90	1.36	71	NS
RT without movement					
1 choice	9.64	49.61	1.66	72	NS
3 choices	1.27	59.01	0.19	73	NS
5 choices	-6.43	79.86	-0.69	73	NS
Arrows Test					
Down median	47.15	55.84	7.26	73	$p < .001$
Side median	50.46	60.88	7.13	73	$p < .001$
Choice RT	20.27	51.75	3.37	73	$p < .001$
Mental Counters Test	-2.93	6.10	-4.14	73	$p < .001$

[a]All values for inspection time are based on raw scores.

The following analyses are based on the full sample (N = 104). Table 9 presents the intercorrelations and unrotated factor loadings for each of the major indices for the computerized battery. The table shows a high degree of intercorrelation among the reaction time variables.

Table 10 reveals the varimax rotated factor matrix for the variables listed in Table 9. Three factors emerged. These were RT, on which all the RT tests loaded; Visual Processing Speed, on which the three IT tasks loaded, and Mental Counters, on which the highest loading was the MCT. Salient factor loadings are underlined.

Table 9

Intercorrelations and Unrotated Factor Loading

	For Computerized Tests													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Loading[a]
1. IT-Adaptive	1.0	-.30**	-.27**	.17	.27**	.24**	.22*	.25**	.23*	.31**	.32**	.33**	-.14	.43
2. IT-Nonadaptive	--	1.0	.09	-.06	-.12	-.16	-.07	-.23**	-.24**	-.09	-.06	-.09	.18*	-.17
3. Perceptual org.	--	--	1.0	-.10	-.19*	-.21*	-.15	-.24**	-.39**	-.10	-.17	-.26**	.23**	-.29
4. Hick move 1	--	--	--	1.0	.73**	.69**	.53**	.57**	.49**	.62**	.56**	.53**	-.10	.77
5. Hick move 3	--	--	--	--	1.0	.84**	.50**	.57**	.57**	.63**	.57**	.60**	-.16	.82
6. Hick move 5	--	--	--	--	--	1.0	.60**	.67**	.67**	.70**	.63**	.64**	-.22*	.88
7. Hick no move 1	--	--	--	--	--	--	1.0	.73**	.66**	.51**	.47**	.50**	-.01	.75
8. Hick no move 3	--	--	--	--	--	--	--	1.0	.78**	.60**	.56**	.50**	-.13	.84
9. Hick no move 5	--	--	--	--	--	--	--	--	1.0	.58**	.57**	.47**	-.20*	.80
10. Arrows Down	--	--	--	--	--	--	--	--	--	1.0	.90**	.62**	-.12	.85
11. Arrows Side	--	--	--	--	--	--	--	--	--	--	1.0	.56**	-.19*	.81
12. Choice RT	--	--	--	--	--	--	--	--	--	--	--	1.0	-.30**	.77
13. Mental Counters Test	--	--	--	--	--	--	--	--	--	--	--	--	1.0	.21
Mean	.00	.33	66	311	396	431	271	322	353	487	546	558	27	
SD	.77	.81	6.0	64	80	92	60.8	61.4	75	81	101	73	7.0	

[a]Factor loadings for first of unrotated matrix for Principal Components factor analysis (total variance accounted for equals 48.3%). Salient loadings are underlined.

*$p < .05$.
**$p < .01$.

Table 10

Varimax Rotated Factor Matrix for Computerized Tests

	Factor 1 Reaction Time	Factor 2 Visual Processing Speed	Factor 3 Mental Counters
IT-Adaptive	.25	.53	-.33
IT-Nonadaptive	.04	-.72	.06
PO Test	-.01	-.62	.09
Hick Move 1	.82	-.04	-.05
Hick Move 3	.82	.09	-.13
Hick Move 5	.87	.15	-.08
Hick No Move 1	.76	.23	.32
Hick No Move 3	.80	.36	.22
Hick No Move 5	.71	.49	.21
Arrows Down	.87	.03	-.20
Arrows Side	.82	.04	-.24
Choice RT	.71	.16	-.40
Mental Counters	-.07	-.24	.75

Table 11 presents the correlations between each of the criterion variables and the major indices for the computerized tests. Inspection of these correlations reveals that the two best correlates of intelligence (as measured by the Raven) were the Arrows Tests ($r = -.28$) and the MCT ($r = .43$). To get a better picture of the relationship between the microcomputerized tests and criterion measures, the significant correlations in Table 11 are corrected for attenuation into Table 12.

Finally, the finding of significant improvement on several indices (see Table 8) left open the question of whether improvement on the microcomputerized tests might reflect high ability. To get at this question, a difference score was computed for each subject for each of the major indices and correlated with each of the criterion variables. Table 13 provides a summary of this analysis. As the table shows, difference scores did not relate well to the criterion variables.

Table 11

Correlations for Criterion Variables and Computerized Tests[a]

	P3	S1	VZ3	GRH	GLH	Raven	SATV	SATM	HSGPA	FRGPA
IT-Adaptive	-.04	-.24*	-.18	.04	.29**	-.07	.00	-.13	-.06	-.15
IT-Nonadaptive	-.02	.11	.23*	.25*	.11	.02	.05	.11	-.06	.14
PO Test	.10	.27*	.15	-.01	-.13	.20*	.21*	-.03	.27*	.16
Hick Move 1	.06	.10	-.09	.22*	.15	.04	.00	-.24*	-.04	-.25*
Hick Move 3	-.11	-.24*	-.19	.10	.10	-.10	.11	-.13	-.14	-.24*
Hick Move 5	-.02	-.26**	-.22*	.03	.00	-.15	.07	-.12	-.16	-.29*
Hick No Move 1	.08	-.07	-.15	.09	-.00	-.00	-.10	-.13	.13	-.13
Hick No Move 3	-.03	-.17	-.11	-.03	.08	-.11	-.14	-.19	-.05	-.27*
Hick No Move 5	-.01	-.30**	-.20*	-.02	-.11	-.15	-.18	-.31**	-.06	-.26**
Arrows Down	.04	-.29**	-.15	.10	.10	-.17	-.10	-.23*	-.06	-.17
Arrows Side	.04	-.37**	-.25*	.03	.10	-.28**	-.14	-.34**	-.05	-.08
Choice RT	-.10	-.06	-.26*	.07	.28**	-.07	.09	.06	-.24*	-.24*
Mental Counters	.02	.20*	.48**	.34**	.06	.43**	.21	.46**	.40**	.14

[a]Not corrected for attenuation.

*p < .05.
**p < .01.

Table 12

Correlations for Criterion Variables and Computerized Tests for Attenuation[a]

	P3	S1	VZ3	GRH	GLH	Raven	SATV	SATM	HSGPA	FRGPA
IT-Adaptive	--	-.48	--	--	.58	--	--	--	--	--
IT-Nonadaptive	--	--	.31	.34	--	--	--	--	--	--
PO Test	--	.31	--	--	--	.23	.25	--	.32	--
Hick Move 1	--	--	--	.28	--	--	--	-.30	--	-.32
Hick Move 3	--	-.28	--	--	--	--	--	--	--	-.28
Hick Move 5	--	-.30	-.25	--	--	--	--	--	--	-.33
Hick No Move 1	--	--	--	--	--	--	--	--	--	--
Hick No Move 3	--	--	--	--	--	--	--	--	--	-.33
Hick No Move 5	--	-.40	-.26	--	--	--	--	-.41	--	-.34
Arrows Down	--	-.34	--	--	--	--	--	-.27	--	--
Arrows Side	--	-.41	-.28	--	--	-.31	--	-.38	--	--
Choice RT	--	--	-.30	--	.33	--	--	--	-.28	-.28
Mental Counters	--	.26	.62	.39	--	.56	--	.60	.52	--

[a]Only those correlations that reached statistical significance, uncorrected for attenuation, are included. All corrections are based on the reliability coefficients presented in Table 6.

Table 13

Correlations of Difference Scores (Improvement)
and Criterion Variables

	P3	S1	VZ3	GRH	GLH	Raven	SATV	SATM	HSGPA	FRGPA
IT-Adaptive	.09	.24*	.07	.07	.45**	.01	.12	.05	.08	-.18
IT-Nonadaptive	-.18	-.00	.11	.09	.08	.01	-.20	.00	-.31**	.12
Perceptual Org.	-.20	-.05	.25*	.31**	-.07	.07	.07	-.09	.08	-.12
Hick Move 1	.18	-.03	.17	.15	.17	-.06	-.16	-.20	.16	-.08
Hick Move 3	-.30**	-.27**	-.20*	-.03	.06	-.01	.22	-.01	.10	.13
Hick Move 5	-.04	-.00	.04	.21	-.10	-.14	.04	.17	-.10	.10
Hick No Move 1	.05	.04	.01	.21	-.06	.16	-.10	-.00	.27*	-.05
Hick No Move 3	-.13	-.06	.25*	.03	.06	.02	.14	.13	.12	.18
Hick No Move 5	-.10	-.15	.08	.30**	-.06	-.01	-.03	-.09	.02	.16
Arrows Down	-.20	-.28*	.00	.09	.04	.02	.08	.00	.04	.16
Arrows Side	-.18	-.25*	-.07	-.07	.11	-.07	.02	-.03	.03	-.01
Choice RT	-.10	.27*	-.06	-.25*	.12	.08	.18	-.06	.29*	.10
MCT	.17	.03	.20	.25*	-.06	.22*	.12	.15	.03	-0.08

*$p < .05$.
**$p < .01$.

DISCUSSION

Overall, the results support the continued development of cognitive speed tests by demonstrating that reliable individual differences exist on certain versions of such tests. The results also verified the previously reported distinction (e.g., Saccuzzo, Larson, & Rimland, 1986; Vernon, 1983) between measures of RT and IT. RT and IT tasks loaded on separate factors and had a different pattern of correlation with the various criterion variables.

Based on our results the following tests deserve further development:

Inspection Time--The IT-nonadaptive test with a horizontal line orientation was clearly the most reliable "line discrimination" task. The task could be further improved by boosting the number of trials from 50 to 75. The estimated test time would be approximately 15 minutes, which should be operationally feasible. Further work on an IT-adaptive test could follow calibration of item difficulties on a large, random sample of subjects.

Considering the more established IT tasks and the new, experimental Perceptual Organization IT task, the latter proved to be the most stable. It yielded test-retest coefficients of .73 (see Table 6) and split-half coefficients of .67 to .79 (see Table 7). Additional work with this test is indicated.

In conclusion, further research on IT should include a 75-item nonadaptive test with horizontal test lines and the Perceptual Organization IT test.

Reaction Time--In considering the RT tests as part of a computerized battery, it is noteworthy that they are highly intercorrelated, load on the same factor, and are related to the same criterion variables. Thus, a wide battery of such tasks is not needed. Rather, an indicated strategy would be to select one or two of the best of these paradigms. Data presented herein indicate that the two most stable of these are the Hick paradigm with movement and the Arrows test. Since the Hick paradigm requires a particular keyboard configuration and the Arrows test does not, the latter is better suited for administration on the military's proposed first generation computerized testing hardware (Hewlett Packard Integral computers), which has a customized keyboard with relatively few response keys. Continued research on the Arrows test is recommended.

Mental Counters--The results with the MCT are also noteworthy. The MCT had a test-retest reliability of .59, with split-half coefficients of .68 and .79. In addition to being somewhat stable, this new, experimental test loaded on its own factor, indicating the measurement of a source of variability not being tapped by either RT or IT tasks. The MCT also produced some of the strongest relationships with criterion variables, correlating (corrected for attenuation) .62, .56, .60, and .52 with the VZ3 test, the Raven, SATM, and HSGPA, respectively. If present results can be confirmed, the MCT may prove to be an excellent choice for inclusion in a well-rounded battery of computerized cognitive tasks.

It is important to emphasize the limitations of the present investigation. First, all of the tasks were, by design, nonverbal. The reliabilities for verbal computerized tasks were not evaluated and may be different from those obtained herein. Second, the data were collected on a college sample of 104 subjects (test-retest coefficients are based on an N of 74). Results may not be fully generalizable to other settings where tests are widely administered, such as the Armed Forces. Replication of the present results on varied populations is therefore advisable.

CONCLUSIONS

The following conclusions appear to be warranted from the data.

1. RT and IT tests load on separate factors, and may have different patterns of validity. Certain tests of each construct have sufficient reliability to justify further development.

2. RT tasks of all types are highly intercorrelated and related similarly to a variety of criterion variables. Consequently, it may not be necessary to have a wide battery of such tasks--one or two well-selected tasks are all that is needed. Of the RT tests administered in the present study, the Arrows test is the best prospect for further research.

3. Of the IT tasks, those involving horizontal lines in a nonadaptive paradigm are by far the most reliable. Increasing the number of trials from 50 to 75 would result in a better test. A nonadaptive, 75 item horizontal line test and the newer Perceptual Organization IT test both deserve further evaluation.

4. The MCT is particularly promising in that it loads on its own factor and thus appears to be tapping into a source of variance different from RT and IT tasks.

5. The continued development and validation of measures of RT, IT, and other variables appears to hold considerable promise for measuring aspects of ability not tapped by conventional psychometric tests.

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